Chapter 3
Social Networks of the Internal Combustion Engine and Automobile

Abstract We describe the network of contributors to the creation of the internal combustion engine and its effects on the early automotive industry. This example has links to the aviation network of invention [Chap. 4] as well as to mathematical Chaos Theory [Chap. 6]

Without the internal combustion engine of the late nineteenth century, there would have been no airplanes, no Wright brothers or Henry Ford. It was the enabling technology of aviation and the enhancing technology of the automobile. Steam power required a source of heat, water and a boiler. The higher energy density of petroleum fuels and the higher temperature of the IC engine with its greater efficiency made it the engine choice of aircraft and automobile designers.

The internal combustion, or IC engine, at first can be seen as an evolutionary extension of the steam engine, utilizing the same kinematic mechanisms, materials, manufacturing methods and marketing base. However the IC engine of the nineteenth century embraced the new science of chemistry and combustion. For nearly two thirds of a century, inventors struggled to couple the dynamic chemistry of exploding gases and volatile fluids with the mechanics of moving iron and steel. And although Nicolas Otto [1832–1891] was crowned the genius-inventor who solved the problem in 1884 with his four-cycle engine, there were dozens of attempts over sixty years to create a practical IC engine (Cummins 1989). The solution, using electrically generated sparks to produce ignition, appeared only after the development of electrical and magnetic science and technology.

The steam engine of the eighteenth century was created by craftsmen and artisans, while the internal combustion engine was designed and built by a new breed of polytechnic trained engineers at the end of the nineteenth century. The exceptions were Lenoir and Otto. The evolution of machine design, culminating in the Redenbacher and Reuleaux schools of machine design in Karlsruhe and Berlin led in part to the development of the practical, internal combustion engine. Designers like Benz, Daimler, Maybach and Diesel were trained in technical universities while others like Lenoir, Otto and Bosch came up in the trades.

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Many evolving elements of technology led to the rise of the internal combustion engine at the end of the nineteenth century, providing evidence for the avalanche or sand pile theory of invention. In addition to knowledge of dynamics of chemical reactions and electrical science, the following components of the internal combustion engine 'knowledge commons' were essential to its development:

- The improvement of materials such as iron and steel processing for steam engine technology.
- The improvement of machining and casting skills for high tolerance machine parts such as pistons, cylinders and valves.
- The advance of thermodynamic principles such as the law of conservation of energy and the law of entropy and theoretical models such as the Carnot cycle.
- The accumulation of capital in the UK, Europe and United States built on steam, rail and telegraph technologies in the late nineteenth century.
- The development of electrical power technology and the search for portable, non-steam based power units.
- The market need for low cost power units for small manufacturing factories.
- The growing popularity of the bicycle and the improvement of roads.

One could add to this list the rise of aviation and the need for lightweight power units for heavier-than-air machines and dirigibles in the early twentieth century. However as we shall see, the tipping point for the development of the IC engine was around 1880–1890, a decade before the Wright Brothers' flights. At the time of the growth of early aviation from 1906–1914, there were dozens of manufacturers of internal combustion engines in both Europe and North America. The tipping point for the automobile century 1885–1890 followed shortly after the exponential rise of gasoline engine technology.

For the historian searching for data to construct a historical network for IC engines, there is a wealth of published reference materials in English, German and French. Some of this material was published a century ago such as Hiscox (1900), Carpenter and Diederichs (1910) and Clerk (1896). For recent IC history books, in German there is Sass (1962) *History of German Internal Combustion Engine Manufacturing*, and the work of Hartenberg (1999), *The Middle Ages of the Internal Combustion Engine 1784–1886*, translated into English by the Society of Automotive Engineers. From these works we can list the main nodes of an IC network.

Principal Nodes in the Internal Combustion Engine Network:

Jean Joseph Etienne Lenoir [1822–1900]: modified a stationary steam engine topology in 1860 by using coal gas as a fuel; sold several hundred engines.

Nikolas August Otto [1832–1891]: inspired by reports of Lenoir engine, designed his own machine with the help of Langen; developed the first commercial four-cycle engine that became the standard thermodynamic model for internal combustion engines to this day. Franz Reuleaux (Chap. 2) was an early consultant to Otto's efforts.

NICOLAUS AUGUST OTTO
1832–1891

Fig. 3.1 Photo of Nicolaus Otto [1832–1891] developed the first practical four-cycle internal combustion engine with Eugen Langen. Co-Founded the Deutz motor company in Germany (Sass 1962; Goldbeck 1964)

Eugen Langen [1833–1895]: business partner of Otto; started Deutz engine company; was a friend and fellow student at Karlsruhe with Franz Reuleaux (Chap. 2).
Gottlieb W. Diamler [1834–1900]: worked for Otto and Langen at Deutz; left with Maybach to form a new company devoted to lightweight engines.
Wilhelm Maybach [1846–1929]: worked as an engine designer for Otto and Langen; later went with Daimler to start their own company near Stuttgart.
Robert Bosch [1861–1942]: German mechanic who developed reliable fuel magneto-ignition systems for the internal combustion engine. He spent some time in New York working for the Edison company. He later worked with Otto's Deutz engine company.
George Brayton [1830–1892]: American engineer who invented a liquid fuel internal combustion engine in 1872, called the 'Ready Motor'. The thermodynamic cycle was later used for gas turbines. An oil-burning Brayton engine was displayed at the 1876 Philadelphia Centennial Exposition at which Franz Reuleaux, a consultant to the Otto-Langen company, was the German ambassador.
Karl Benz [1844–1929]: German mechanical engineer who developed an early two cycle gas engine and went on the design and build a gas engine-powered three wheeled carriage. He co-founded the company Benz & Cie. In 1899, they sold over 500 automobiles, and over 3000 vehicles in 1902 a year before Ford started his Model A and Model T company.

Rudolf Diesel [1869–1945]: French born, German educated mechanical engineer who developed a compression-ignition engine, known today as the 'diesel engine'. He studied with Carl von Linde in Munich who had developed refrigeration machines (See e.g. Chap. 7).

3.1 Growth of Technical Events for the Internal Combustion Engine

A measure of the exponential growth of the IC engine is the number of cumulative events such as patents issued. Using data from Carpenter and Diederichs (1910) we see a gradual rise in the early decades of the nineteenth century and a sharp rise beginning in the 1880s decade illustrated in Fig. 3.2.

The exponential growth of the IC engine at the end of the nineteenth century, can be measured in several ways. For example the size of the Otto four-cycle engine in 1878 was 4 BHP, in 1893 it was 200 BHP and by 1908 it was 4000 BHP (Carpenter and Diederichs 1910). This is shown in Fig. 3.3a. When plotted on a logarithmic vertical scale versus years the slope is a straight line as shown in Fig. 3.3b.

As indicated in the opening paragraph, this rise of historical IC events can be correlated with the evolution of both scientific advances in thermodynamics and materials processing as well as manufacturing technologies. Another measure is the growth of US patents issued as listed in Hiscox (1900) shown in Fig. 3.4. Our thesis in this book is that this exponential rise in the measures of innovation is correlated with the growth of a innovation social network.

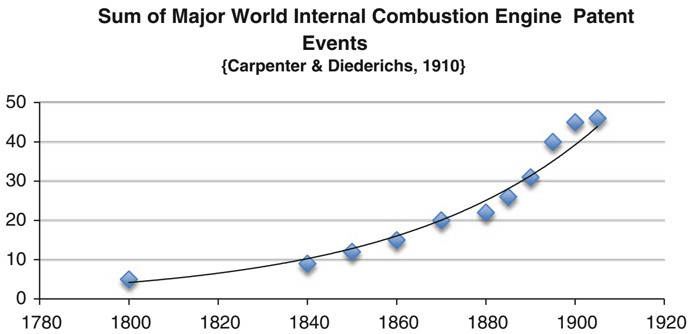

Fig. 3.2 Growth of the number of significant international patents related to the internal combustion engine as reported in Carpenter and Diederichs (1910). The *solid line* is a best fit exponential curve using Excel

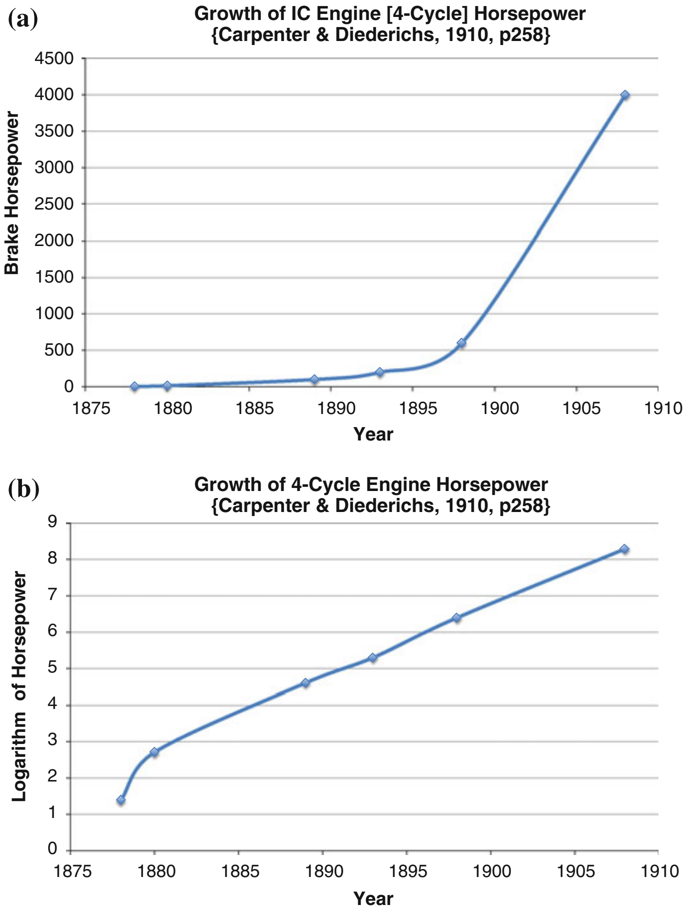

Fig. 3.3 **a** Plot of IC engine brake horsepower (BHP) for Otto engines from 1880–1908. **b** Data in Fig. 3.3a plotted on a logarithmic vertical scale. The *straight line* is an indication of exponential increase in engine power (Carpenter and Diederichs 1910)

3.2 The Standard Model for Internal Combustion Engine Innovation

Before discussing the social network attendant to the internal combustion engine, we summarize the conventional narrative that usually anoints Etienne Lenoir and Nikolas Otto as the genius-inventors of this technology. By the mid nineteenth century, the steam engine had diffused and matured in many applications beyond its original role of pumping water out of the deep Cornish tin mines of England a century earlier. By 1850, the steam engine was a key power source in England, Germany, Belgium and to a lesser extent France. Accompanying this technology, a vast infrastructure

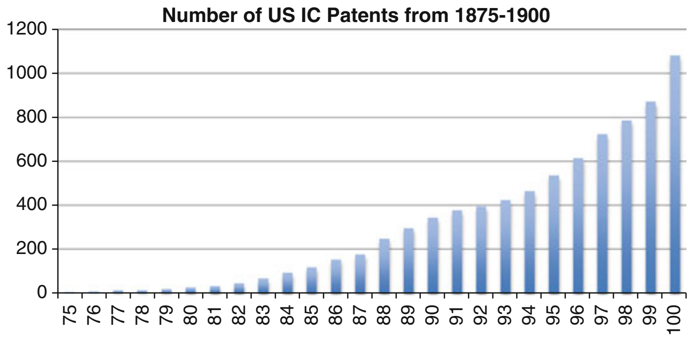

Fig. 3.4 Number of US patents related to internal combustion engines from 1875–1900, showing cumulative patents (Hiscox 1897)

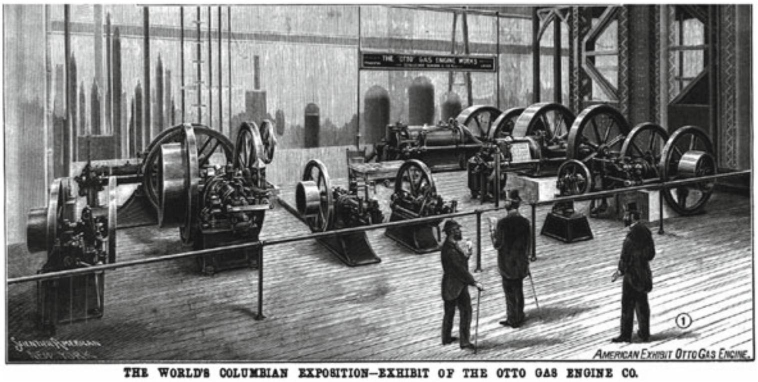

Fig. 3.5 Nicolaus Otto's display of internal combustion engines at the Chicago Columbian Exposition, cover of Scientific American (1893)

of machine shops and machine tool education grew through apprenticeships and polytechnic colleges, especially in England and Germany, out of which came the early successes of Lenoir, Otto, Daimler and Maybach. With the rise of large steam engine powered manufacturing enterprises, there grew a desire to find an alternative power source that was smaller, lightweight and more portable and did not depend on coal and could be used for transportation on land, water and air vehicles. Around 1810, George Cayley, one of the early visionaries of heavier-than-air vehicles, recognized the need for an alternate to steam.

Out of this milieu, Lenoir, using a conventional, horizontal, double-acting steam engine topology, built an engine without a furnace, boiler and steam using an explosive mixture of coal gas. Around 1860, he began to market these small 3 HP engines with great publicity and market interest. As the story goes, Otto read of Lenoir's exploits and sought to make a more efficient design. In 1866, Otto teamed up with Eugen Langen to produce a vertical single-cylinder engine that more than doubled

the efficiency of the Lenoir engine and won the Napoleonic prize at the Paris Exposition of 1867. This recognition captured a large part of the market away from Lenoir and established Otto and Langen as major gas engine manufacturers producing over 2000 engines between 1866 and 1876. Otto and Langen exhibited some engines at the Centennial Exposition of 1876 in Philadelphia as well as at the Chicago Columbian Exposition of 1893 (Fig. 3.5). During this time Otto worked to perfect a new engine based on a four-cycle system. Otto and Langen opened up franchises in Philadelphia, Vienna, England and France to become the world's largest manufacturer of gas engines. Otto also hired Daimler and Maybach as engine designers. Daimler became manager of the main manufacturing factory in Deutz, Germany near Cologne.

In the period of Otto patent protection of the four-cycle engine from 1876–1884, other competitors such as Clerk in Scotland began working on two-cycle engines. Also the growing scientific field of thermodynamics brought forth new engines such as the Brayton engine in the United States. As the story continues, Daimler and Maybach split with Otto and Langen and set up a factory in Cannstatt Germany near Stuttgart to manufacture lightweight, high-speed engines for vehicles that ran on petroleum based gasoline. Karl Benz had a similar vision and brought out a tricycle vehicle with gas engine in 1885. Daimler and Maybach showcased a four-wheel vehicle in 1886 and the automobile age was born. By the turn of the century, the gas engine industry was maturing and expanding in a dozen countries with over a thousand patents awarded in gas engine technology in the US alone. This development took place over four decades and was now ready to be exploited by Siemens and his growing electric generator technology as well as by a group of aviation dreamers led by the Wright Brothers.

This narrative gives the primary facts and is compact enough to fit on a page in a book on the history of inventions or machines. But a more detailed reading of primary sources reveals a more complex story. There were many other major and minor players in this evolution that gives a richer understanding of how this key technology evolved and enabled other new technologies dependent on it to also evolve.

3.2.1 A Network Model for Internal Combustion Engine Innovation

Much of the data enabling the construction of the interconnected nodes in the internal combustion engine network comes from early textbooks such as Carpenter and Diederichs (1910) of Cornell University and Hiscox (1900) or the two-volume work of British IC engine pioneer Dugald Clerk (1896). Another valuable source is the scholarly work of Hardenberg (1999) whose detailed description of original patents from the eighteenth and nineteenth centuries has been published by the Society of Automobile Engineers. Also biographies of some of the German players by German speaking authors such as Diesel et al. (1960), provided more links and nodes than

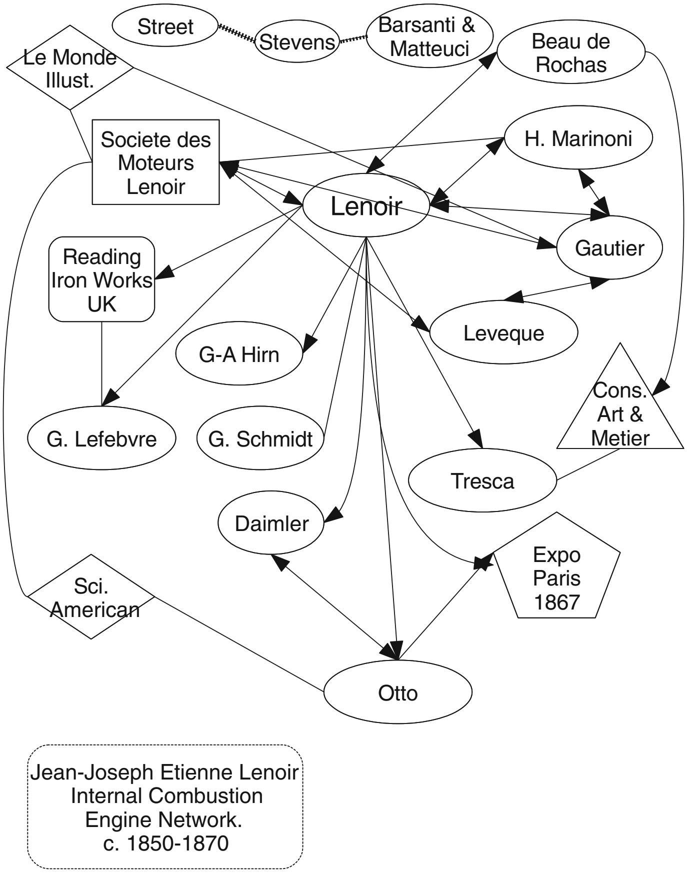

Fig. 3.6 Partial historical network centered around Lenoir his company Societe Lenoir related to his engines of 1860 and 1861 (Cummins 1989; Slade 1866)

that found in thumbnail histories. More difficult to find in English is biographical information about French IC pioneer, Jean Joseph Etienne Lenoir [1822–1900] so the links to his node are not as well known.

A partial network centered around Lenoir and his engine (Fig. 3.6), can be constructed from the Society of Automotive Engineers publication by Hardenberg (1999), pp. 235–266.

An example of a sub-network for the internal combustion engine centered around Otto and Germany is shown in Fig. 3.7, that led to the lightweight engine of Daimler (Fig. 3.8).

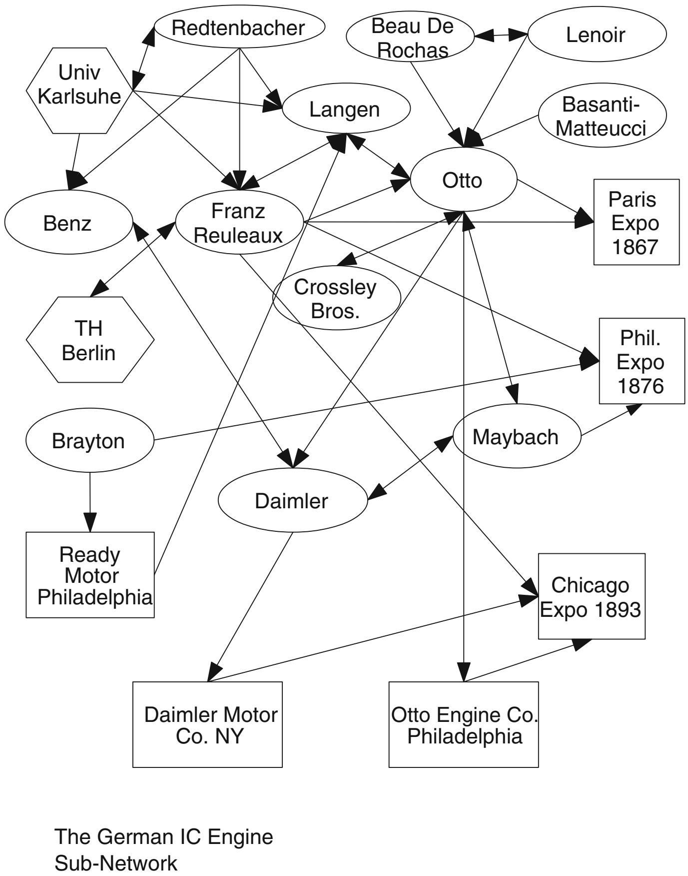

Fig. 3.7 Sub-network for the internal combustion engine 1860–1890, centered around Otto and other German Engineers

3.3 Pre-Lenoir and Otto IC Engines: Linear Growth 1800–1880

The title of Horst Hardenberg's seminal work *The Middle Ages of the Internal Combustion Engine* 1794–1886, gives a teaser to the argument that Lenoir and Otto were not the only nodes in the genius model of IC engine development. Hartenberg begins with a short homage to Leonardo da Vinci and Christiaan Huygens gunpowder engine proposals of the late fifteenth and seventeenth centuries, but then describes and analyzes a dozen or more IC engines spanning six decades where both patent records and working IC models were built. He also uses thermodynamic principles to compare the different machines as to efficiency and power.

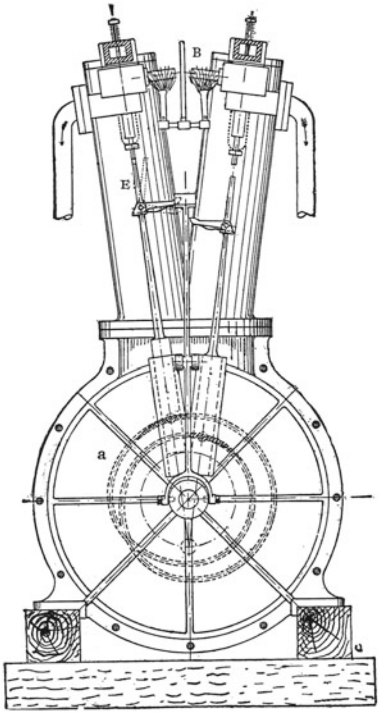

Fig. 3.8 Gottlieb Daimler's two cylinder lightweight internal combustion engine., Cannstatt Germany. (Sibley Journal of Engineering, Cornell University, Ithaca, NY, p. 229, Vol XI, 1896–1897) Specifications; 4.45 HP, 576 RPM, Piston Diameter = 3.425", Stroke = $0.525'$. This motor was designed for marine application

These early IC machines include the work of: (See e.g. Carpenter and Diederichs 1910; Clerk 1896; Hardenberg 1999).

Robert Street [1794] British; engine used spirits of tar or turpentine to drive a piston vertically and move a levered pump. The piston was gravity returned.
John Steven [1798] American; Columbia University trained lawyer and designer of steam driven boats built an alcohol fired free piston engine with the help of Marc Isambard Brunel, a British engineer who later achieved much fame in the UK.
Lebon [1804] French civil engineer who patented a gas ignited piston engine.
Niepce brothers [1806] Built a pulverized coal, combustion engine; report given to the institute of France.
William Cecil [1820] British Reverend Cecil built the first hydrogen–air combustion engine and demonstrated it before the Cambridge Philosophical Society.
Samuel Brown [1823], Built and demonstrated, in England and the US, a pistonless gas fired water wheel for canal pumping applications. Patents issued 1823, 1826.
Lemuel Wellman Wright [1834] Coal gas combustion, double acting engine designed similar to a Watt steam engine with water cooled jackets.
William Barnett [1838] Similar to the Wright engine with timed ignition with a rotary slide flame valve. Designed three engines, but no evidence they were built.

Eugenio Barsanti and Felice Matteucci [1856] Spanish teacher Barsanti and engineer Matteucci, built a vertically driven piston engine with a combustible gas–air mixture. Similar to the first Otto-Langen engine.
Pierre-Constant Hugon [1858, 1864] Director of a gas company in Paris patented and built an indirect gas engine where the combustion occurs in a separate chamber. Demonstrated at the 1867 Universal Exposition in Paris.
Christian Reithmann [1860–1869] Bavarian watch maker Reithmann and his technician Ainmiller designed both single acting and double acting gas engines.
George Brayton [1872] American machinist designed and built gas engine more efficient than then popular Lenoir engine. Professor Robert Thurston of Stevens Tech tested the engine and published results.
Dugald Clerk [1880] Scottish chemist designed and built a two-cycle engine.

The names in the above litany of early inventors of IC engines will mean very little to most readers. Greater details about them and their inventions can be found in Hardenberg (1999), available in English translation or German. They are listed here to convey the hidden complexity of the historical innovation networks in Figs. 3.6 and 3.7. They could have been added as nodes to the Lenoir or Otto networks, but discovering the links between these secondary nodes and principal nodes is a difficult task.

A second reason for the mention of these inventors is to emphasize the existence of a *knowledge commons*. The word 'commons' is used here to denote a public space or free information as exists in technical and scientific magazines, or expositions and public exhibitions and demonstrations. A knowledge commons existed in many technologies such as radio electronics or the early days of computer programming. A knowledge commons is also transmitted through 'word of mouth' and is different from the artisan and workshop secret knowledge that was often guarded in the early part of the industrial revolution. Then and now the very filing of a patent disclosed what was possible, such that clever engineers could find ways around the patent. That is why even today some companies prefer the trade secret method rather than the patent disclosure to deter finding paths to their product or process secrets. Although inventors are famous for preferring solitude to human company, they are both curious and clever and will almost always seek information from the knowledge commons.

Following our methodology we plot the number of Hartenberg's internal combustion engine events as listed above versus time, as shown in Fig. 3.9. The graph reveals a linear-like growth in the IC commons knowledge base from 1790–1880.

Although one can approximately fit a linear curve to the data of Fig. 3.9, one might also fit a multi-linear, stepwise curve with plateaus around 1810, 1830, and 1850 suggesting an uneven rate of progress with fits and starts of activity. However this may be taking the data too seriously in that we have a relatively low number of events compared to the later exponential rise of patents shown in Fig. 3.4. The evidence presented by Hardenberg does follow other innovations where there is a linear rate of innovation before the sharp exponential rise that is characteristic of a new revolution in technology. This data also supports the so-called 'sand-pile' model

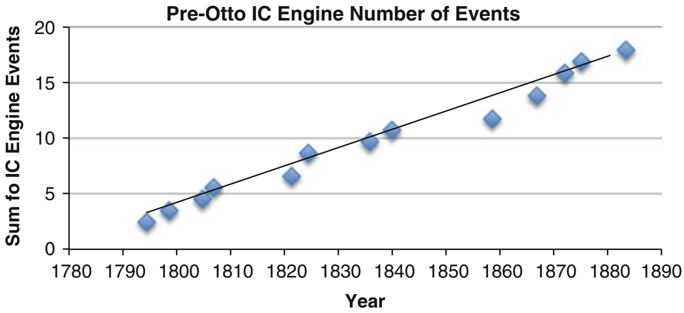

Fig. 3.9 Plot of the sum of major IC events in Hardenberg's *Middle Ages of the IC Engine* (1999) showing a linear or multi-linear progression of the IC knowledge base

of innovation where the knowledge commons accumulates to a critical point where it triggers a sharp growth in the innovation network.

Missing in the IC networks in Figs. 3.6 and 3.7, was the myriad numbers of engine and parts fabricators. Some like Lenoir and Otto were able to secure capital to start their own companies. But other inventors used local machine shops to build prototypes. Also licenses were issued to outside firms such as Francis and William Crossley of Manchester, one of the largest producers of early Otto engines.

3.4 The Evolution of the Automobile

Closely coupled to the rise of internal combustion engine technology is the evolution of the automobile. Again the classic icons in Germany are Benz and Daimler. In the United States, Alexander Winton and the Duryea Brothers were early pioneers but in the history books Henry Ford was anointed as the genius inventor-entrepreneur. As has been shown in the previous examples in this book, the path to the 'horseless carriage' involved many other players, some of whom were part of the IC engine social network.

The automobile was not just an engine on wheels. It was the marriage of a wheeled carriage with a power plant of steam, electric, gas or petroleum. One of the first prototypes was built in 1771 by the French engineer Nicolas Joseph Cugnot [1725–1804], who placed a steam engine on a four-wheeled carriage. Cugnot had studied the machine books of Leupold (See Chap. 2).

The spoked-wheel had undergone more than three millennia of development including the appearance of pneumatic tires in the middle nineteenth century. After the French Revolution, scientific carriage design had also undergone development that produced elliptical spring suspension, lightweight frames, cantered wheels and turntable axles. By the time the IC engine appeared, there was a large industry of carriage makers as well as bicycle manufacturers and artisans with skills to repair

both kinds of land vehicles. In addition, the craze for bicycles had created a need for improved roads.

These supporting technologies for the horseless carriage proceeded in a linear progression in the nineteenth century. In 1885, the appearance of Diamler and Maybach's lightweight two-cylinder internal combustion engine, that ran on liquid petroleum, triggered an exponential avalanche in the advance of the motor car as seen in several measures: number of patents, number of manufacturers, innovation event growth or increase of engine horsepower. Thus the social innovation network for the internal combustion engine, that began with Lenoir around 1860, set in motion a closely related social innovation network for the horseless carriage. This rise began around 1885 at least a decade before Henry Ford began tinkering with his friends in his garage with a horseless carriage, and two decades before Ford developed the famous Model T in the United States.

3.5 The Classic Timeline for the Automobile

As we have proceeded in the case of the steam engine and internal combustion engines, we use classic narrative histories as sources to construct timeline growth curves and innovation network diagrams. There are hundreds of books on the automobile as well as sources on the World Wide Web. In this chapter we have used the translation of the German work of Erik Eckermann (2001) published by the Society of Automotive Engineers (SAE), Merki (2002), as well as James Flink's *America Adopts the Automobile* (1970).

Most historical reviews begin with Nicolas J. Cugnot's steam carriage of 1771, and Oliver Evans amphibious vehicle of 1805 (Orukter Amphibolos). Also Richard Trevithick of railroad fame developed a road steam car in 1803. The forerunner of the gas-powered car was Lenoir's three wheeled vehicle of 1863. But steam powered and early gas engine powered vehicles were too heavy and cumbersome. It was the development of lightweight gasoline powered vehicles of Benz, Daimler and Maybach, as well as the development of ignition technology that triggered an avalanche in automotive technology innovation. Although the power plant originated in Germany, the early development of manufactured vehicles began in France, often using German licensed engines. The automobile is an example of what is called today 'systems engineering' and the French had key elements in the automotive system development including better roads than Germany that originated in the Napoleonic era. The French group included Edouard Delamare-Deboutteulle [1884], Panhard et Levassor [1887], Armand Peugeot [1890] who used a Daimler engine, Albert de Dion [1894], Emile Delahaye [1894], Leon Bolee [1896] and the Renault brothers who sold their first car in 1898. The Automobile Club of France was formed in 1895.

In the United States there is the famous automobile patent of George B. Selden [1879–1895] who never built a working vehicle but whose legal maneuvering set back American efforts, a precursor of the Wright Brother's legacy in aviation. The Duryea brothers J. Frank and Charles E. produced a car in 1893 after reading about Benz's

vehicle in the 1889 Scientific American. Around 1896 Hiram P. Maxim, Alexander Winton, Charles. B. King and Random E. Olds as well as Henry Ford and his friends build prototype automobiles. Also in 1895 two new automobile magazines appeared, *Motorcycle* and *Horseless Age*, in which they reported over 500 applications to the US Patent office related to automobiles. At this time there appeared a number of electric cars as well as steam cars such as the Stanley Steamer of 1898. By 1899, there were about 30 American automobile companies. In both France and the US automobile racing excited public interest in the automobile, stimulating sales of horseless vehicles.

In 1900 there was an Automobile Show in Madison Square Garden and the Automobile Club of America was formed out of a number of state automobile clubs. In the 1901 Auto Show in New York City there were 58 steam, 23 electric and 58 gasoline cars on show (Flink 1970). But by 1905, there were only 9 steam and 20 electric vehicles compared to 219 gasoline powered automobiles on show. As part of the avalanche of technology in internal combustion engines, engineers could produce lightweight engines of 60 hp in a Mercedes in 1903, 120 times more powerful than Daimler's original 0.5 HP engine of 1885 and well beyond the pace of electric and steam car development.

Using the principal events in the development of the automobile as narrated in Eckermann (2001) and Flink (1970) one can plot the integrated number of events versus time as shown in Fig. 3.10. Like so many other examples of innovation in this book and other sources, the development of the automobile shows an exponential growth in the early period of technical ideas before economic measures show similar growth. In another plot (Fig. 3.11), one can see a growth in cars registered in the US with a sudden rise around 1915 compared with the rise in technical ideas beginning in 1885, a twenty year lag time.

In addition to specific person nodes, industrial company nodes and institutions, such as the Royal Automobile Society, there existed a large knowledge base in internal combustion engine and automotive technology. This knowledge base could be accessed by a novice through magazines and newspapers as well as listening to anecdotal case histories. As prototypes appeared they could not be hidden in a shop; they were paraded on public streets to both public amazement and condemnation. Also parts, tools and automotive supplies could be obtained from a growing number of manufacturers. The automobile is an example of a systems engineering technology that relies not on a singular technical breakthrough, but on the skillful integration of many parts and systems; engine, transmission, electrical system, carburetor, axles and wheels. Much of the initial undercarriage systems were directly adapted from the horse carriage business.

Thus when we read of Henry Ford designing his own four-cycle engine in 1895 or the Wright brothers creating their own lightweight engine in 1903, one must realize that each had access to what we may call a "common knowledge node" in the social innovation network.

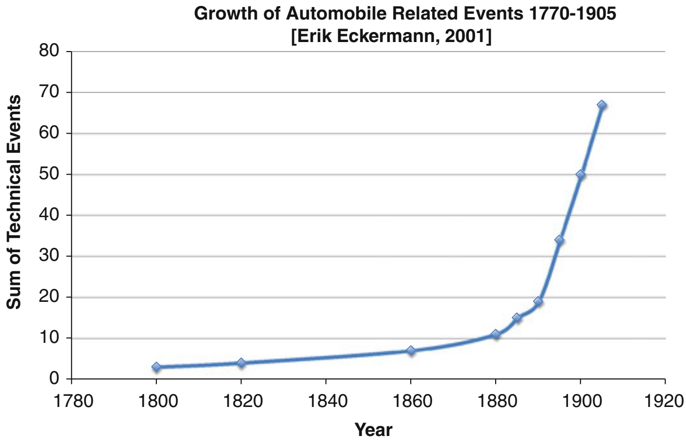

Fig. 3.10 Intergrated number of technical events in the development of the automobile showing a sharp rise around 1885 the time of Daimler and Maybach's lightweight IC engine (Eckermann 2001, Flink 1970, plus several internet websites)

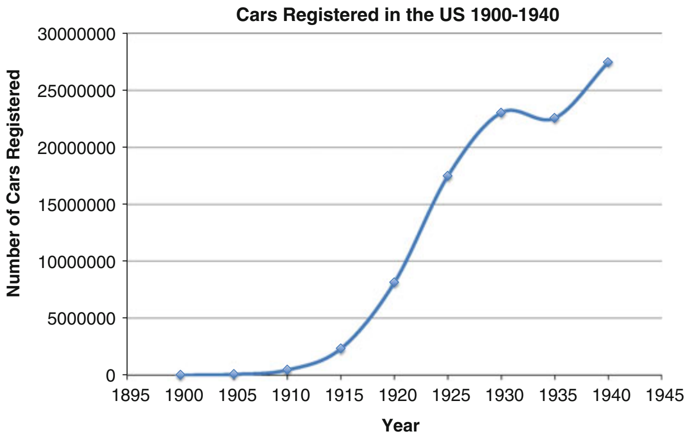

Fig. 3.11 Number of cars registered in the US from 1900–1940 (US Department of Trans. Federal Highway Administration, *The 2000 World Almanac*)

3.5.1 The Henry Ford Model A and Model T Automobile Networks

Using narrative data from a recent biography of Henry Ford by Steven Watts (2006), a partial historical innovation network surrounding Henry Ford is shown in Fig. 3.12. This is necessarily a 'star' shaped network since it is constructed primarily around the life of Ford. A more comprehensive innovation network for automobiles would require the integration with the biographical networks of many other inventors.

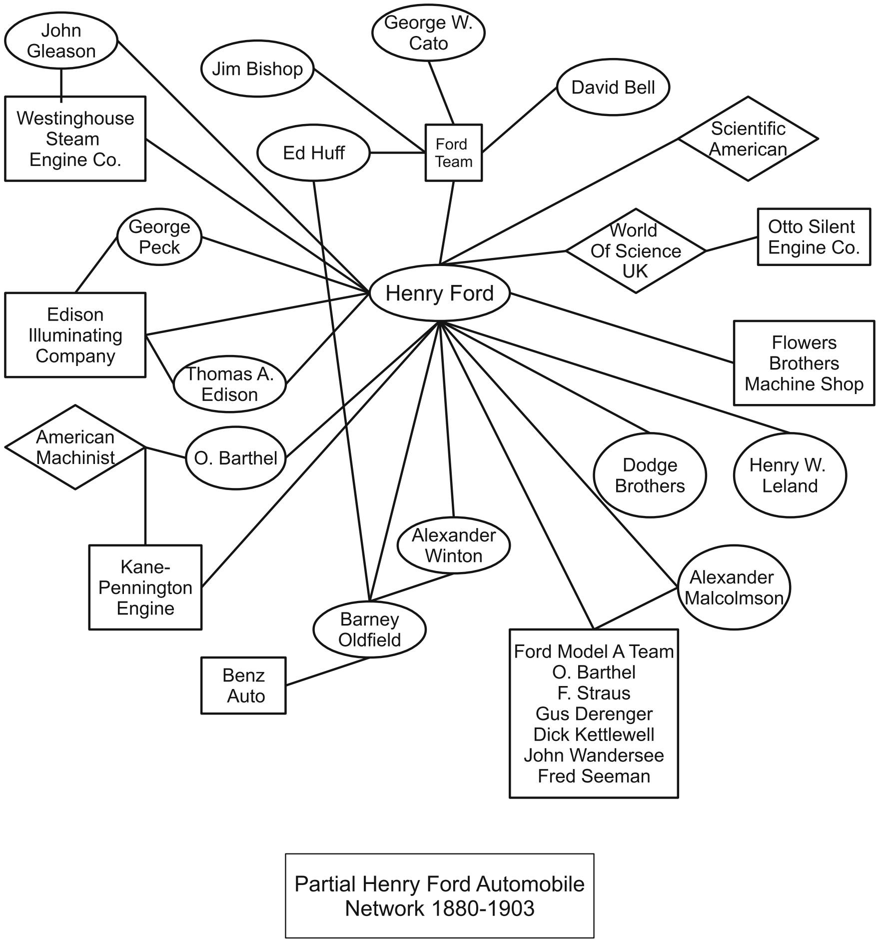

Fig. 3.12 Partial Henry Ford automobile star network based on the biography of Henry Ford by Watts (2006)

A brief guide to some of the nodes in the Henry Ford Network in Fig. 3.12 is as follows:

Otto engine—World of Science and Scientific American; according to Watts (2006), Ford read about the Otto engine in the British magazine *World of Science*. He was also a reader of *Scientific American*, which in its day featured new technical developments such as the lightweight two-cylinder Diamler engine (Fig. 3.8). Also by the mid 1890s, there were new magazines such as *Horseless Age* and *The Automobile and Motor Review* devoted to automobiles.

Westinghouse engine technology; Ford worked for a farmer named Gleason who had purchased a new Westinghouse portable steam engine for threshing and cutting timber. Ford became a demonstrator and mechanic for the machine, taking it around to

different farms. He was subsequently hired by a regional manager for Westinghouse, John Cheeney, to maintain and repair these steam engines. His experience with steam engines on a carriage led him to dream about building a 'horseless carriage'.
Ford backyard garage horseless carriage team; While working for Edison Illuminating Company maintaining steam engines, circa 1896, he brought together a team of mechanics to build a 'horseless carriage' in a shack near the Edison plant in Detroit. The vehicle was called the *Quadricycle,* and was driven around town and attracted a number of investors in the first Ford company that eventually failed.
Edison company sub-network; Through Ford's experience at the Edison Illuminating Company in Detroit, he met Thomas Edison himself and visited Menlo Park. The Edison Company manager George Peck also introduced Ford to future investors in his 'horseless carriage' schemes. Like all successful inventors and entrepreneurs such as James Watt and Samuel Morse, success depended on developing a network of investors.
Automobile racing sub-network; After the failure of his first company, Ford began working on a 80 hp racing car called '999'. He attracted the attention of a then famous race-car driver named Barney Oldfield who had driven for the automobile maker Alexander Winton [1860–1932]. Oldfield had also driven a Benz auto racing car before working for Ford setting a record 131 mph record at Datona Beach Florida. In 1902 the Ford-Oldfield car had a publicized race with one of Winton's cars and won, attracting publicity and new investors for his latest venture the 'Model A'. The following week he incorporated "The Ford Motor Company".
Model A Fordsub-network; The Model A vehicle was built by a team of Ford friends and mechanics colleagues around 1903 with capital from Alexander Y. Malcolmson that launched Ford's automotive empire.

A similar pattern of racing machines and daredevil antics accompanied the early aviation development discussed in Chap. 4. Behind each technology was the push to develop new lightweight, more power intensive internal combustion engines.

According to the integrated event timeline curve in Fig. 3.10, Ford's activities were in the height of the exponential rise in automobile technology. In the early days of the Ford Motor Co. 1903–1906 they produced 13,721 vehicles. However the Old's company produced 17,600 vehicles in this four-year period. From 1906–1910, Ford produced over 83,600 vehicles and Buick would produce close to 60,000 vehicles. Ford would emerge as the leader but about half of American automobiles would still be built by companies other than Ford. While Ford was the 'best among equals' in producing cheap automobiles, he was not the lone genius in the field.

3.5.2 Zipf's law: For Auto Makers

In Chap. 1 we mentioned the research of Yale physicist Derek J. de Solla-Price (1963) who applied statistics to the research publications of scientists. His work followed earlier work of Harvard professor George K. Zipf (1949) who applied statistical ranking to human social entities from word rank in novels to the size of cities. Some

of these disparate data sets fall into a mathematical function called *power laws*. When data is plotted on logarithmic scales the points lie on a straight line indicating a mathematical relationship of the form $y = x^{-s}$, where 's' is the negative slope of the Log–Log graph: where 'y' is plotted on the vertical axis and 'x' is plotted on the horizontal axis.

Recently these power law relationships have been found in the statistics of modern social networks (Bak 1996; Buchanan 2000). In the case of population of cities, this law says that there is no average city. There are a few large cities, a greater number of moderate cities and many more smaller cities. This can be seen for the largest US cities in 1900 shown in Fig. 3.13 top. What is surprising is that this same power law type relation holds for the ranking of US automobile makers in the early years of the industry, shown in Fig. 3.13 bottom. There is no attempt here to claim that the ranking of cities is related to the ranking of auto manufacturers, except that if there is a sociological principle that bigger human groups get bigger and smaller human groups do not get as big, then this may also apply to auto makers. If from 1900 to 2013, New York City has dominated the US population charts in spite of widespread demographic changes, then it is not surprising that Ford dominated the US market from 1906 to 1930. Whatever human dynamics existed a century ago in the decisions as to where people lived, there might have been similar social pressures as to what brands they bought.

What has ranking of automobile brands have to do with historical social networks for the development of the automobile? In Chap. 1 we discussed the construction of social network graphs and how one could assign value or scales to the nodes. In the automobile network, manufacturing companies act as nodes in the same way as person nodes. The ranking of companies by the number of cars sold is one measure of the strength of their node in the network. Similarly one can see that although innovation networks diminish the role of the hero-inventor, the hero-inventor node often dominates the other nodes in the number of links to and from his or her node. In Chap. 4, we show that the number of links versus nodes seems to follow a rough power-law and that the hero-inventor, namely the Wright brothers, had the largest number of links.

The star network of Ford in Fig. 3.12 could be duplicated for a dozen or more principal nodes from Karl Benz and Robert Bosch in Germany to Emile Levassor and Louis Renault in France, and Ransom Olds and Charles and Frank Duryea in the United States. These star networks could be stitched together to form a large quilt with 100 or more nodes and hundreds of links (See e.g. the *World History of the Automobile*, by Erik Eckermann 2001).

We shall not pursue this super network for automobile technology in this chapter. Instead, in the next chapter we will construct a more integrated network for the related technology of heavier-than-air flying machines, employing an influence matrix and applying modern measures of network theory to early aviation. However the path to analyzing the social network for automobile technology has been laid out here.

In this chapter we have tried to make the case for the evolutionary development of the internal combustion engine as a seamless transition from steam engine technology and incorporating thermodynamics and kinematics of machines. From the

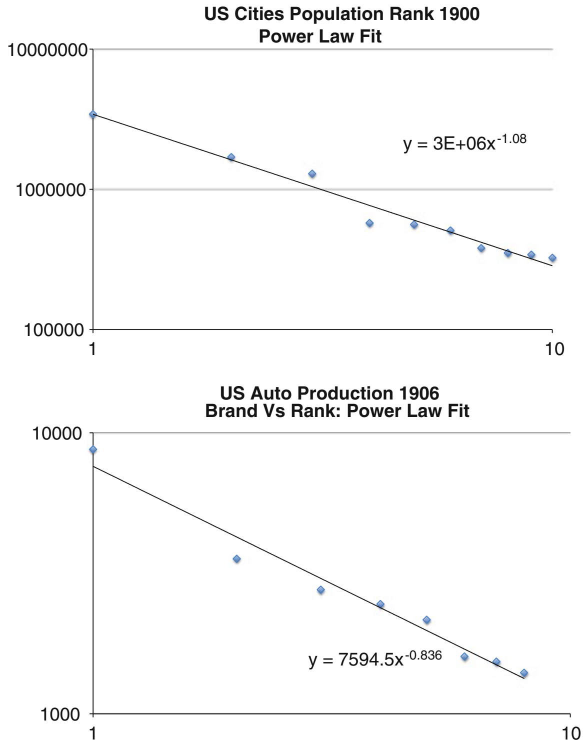

Fig. 3.13 *Top* US population of cities versus rank plotted on logarithmic scales. The top cities are New York, Chicago, Philadelphia, St. Louis. *Bottom* US automobile production for 1906, plotted on logarithmic scales. The brands were; Ford, Cadillac, Rambler, REO Motor Car Co., Maxwell, Oldsmobile, White and Buick

moment a lightweight portable energy source became possible, a worldwide rush to apply this technology began around 1885–1890 with applications to manufacturing, automobiles, electrical power and aviation.

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